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Study of Ship Resistance Characteristics in Pack Ice Fields

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ABSTRACT

During the melting seasons of the Arctic, the ice condition is quite similar to pack ice fields; thus, a major component of ship resistance arises from momentum exchange between the ship and the broken ice floe. In particular, ice concentration and thickness will lead to significant changes in the ship performance. The aim of this research is to understand ship resistance characteristics when navigating in pack ice fields and investigate the factors that influence of the magnitude of resistance in the model tests in an ice tank. Various channel widths, ice concentrations, and thicknesses are considered, and model tests were conducted in the Korea Research Institute of Ships and Ocean Engineering (KRISO) ice tank. In this paper, the test results are analyzed, and the ship resistance characteristics in pack ice are then discussed.

KEY WORDS: Pack ice fields; Ice concentration; Ship resistance characteristics

INTRODUCTION

It is known that ship performance in pack ice conditions depends on ice concentration and thickness. Ship resistance in pack ice is a therefore significant concern for ship builders when considering the summer operation of vessels in ice-covered waters. Model tests in an ice tank can provide ship resistance characteristics. The international towing tank conference (ITTC) provides ice test procedures and the analysis methods (ITTC, 2017). In particular, preparation methods for various ice conditions, such as level ice, brash ice, and ice ridge, are introduced in detail. However, the descriptions of the model test methods in pack ice conditions are quite simple, consisting of a general description of the definition of the ice concentration and the classification of ice floe size in the pack ice fields. Meanwhile, it is very difficult to simulate full-scale environmental conditions using ice model tests in pack ice conditions and obtain quantitative results that have a high accuracy and are repeatable and reproducible.

Several studies have been performed to investigate ship performance in pack ice conditions. For example, Grochowalski and Hermanski (2011) studied ship resistance and propulsion characteristics and introduced a new method for predicting ship resistance in pack ice. Kim, et al. (2013) studied the resistance performance of an icebreaking cargo vessel in pack ice conditions both numerically and experimentally.

The main purpose of this study is to better understand ship performance and ship resistance characteristics in pack ice. The effect of channel width in pack ice tests is investigated, and then a reasonable channel width under this condition is derived from ice model test results. In addition, ship resistance characteristics in pack ice conditions with various ice thicknesses and concentrations are discussed. These results may be useful in improving ice model test methods for pack ice, and the study provides further background knowledge regarding ship resistance characteristics.

MODEL TESTS AND RESULTS

A series of ice model tests was carried out at the ice tank of the Korea Research Institute of Ships and Ocean Engineering (KRISO) to better understand the characteristics of ship resistance in pack ice. The ship model of the Korean icebreaking research vessel *Araon* was used in this study. The required operational icebreaking performance is 3 knots in a continuous icebreaking process with level ice of thickness of 1.0 m. The specific dimensions of the model ship are summarized in Table 1.

Table 1. Principal particulars of the ship model (Jeong, et al., 2015)

Scale (λ = 18.667)	Model
Length between perpendiculars (m)	5.01
Maximum beam (m)	1.02
Design waterline (m)	0.36
Stem angle (°)	35.0
Waterline entrance angle (°)	34.0
Displacement (kg)	1142

The model tests focused on boundary conditions to investigate how much influence the channel width had on the magnitude of ship resistance; various channel widths were thus considered. The first model test conditions are summarized in Table 2. During the tests, the model ship was towed by the main carriage and was constrained in surge motion and others were free. The physical properties of each ice sheet were checked before and after each test in accordance with KRISO's procedures (Jeong, et al., 2017). In this study, the density of the model ice was 870 to 880 kg/m^3, and the frictional coefficient between the ship and model ice was 0.05. The broken ice floe diameter was approximately 30% of the model ship's beam. This value is based on observation data from a full-scale ice trial of the *Araon* during the arctic summer expedition in 2017 around the East Siberian Sea. The ice model test process is illustrated in Figure 1.

Table 2. First model test conditions

Test No.	Channel width	Ice thickness (mm)	Ice concentration (%)
100A	4.0×B	26	80
100B	8.0×B	26	80

B denotes the model ship's beam

The pack ice resistances were analyzed for each channel width. The resistance characteristics are given in Figure 2. The difference in pack ice resistance was approximately 11.0 N for each model ship speed. The ice model test results showed that the channel width can affect the magnitude of ship resistance in pack ice. Therefore, ice model tests for various channel widths were conducted to identify the effect of channel width. The second test conditions are summarized in Table 3, and the prepared test channel conditions are depicted in Figure 3.

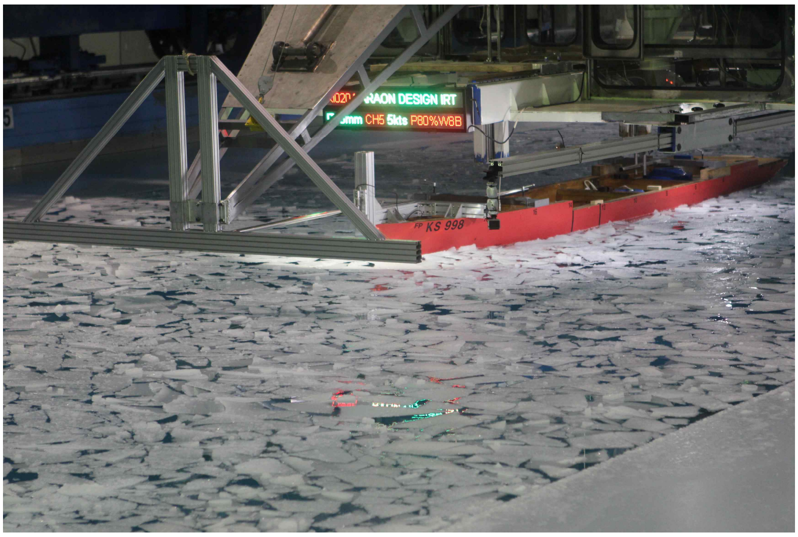

Figure 1. Model test at 8 times the beam of the model ship and 80% ice concentration

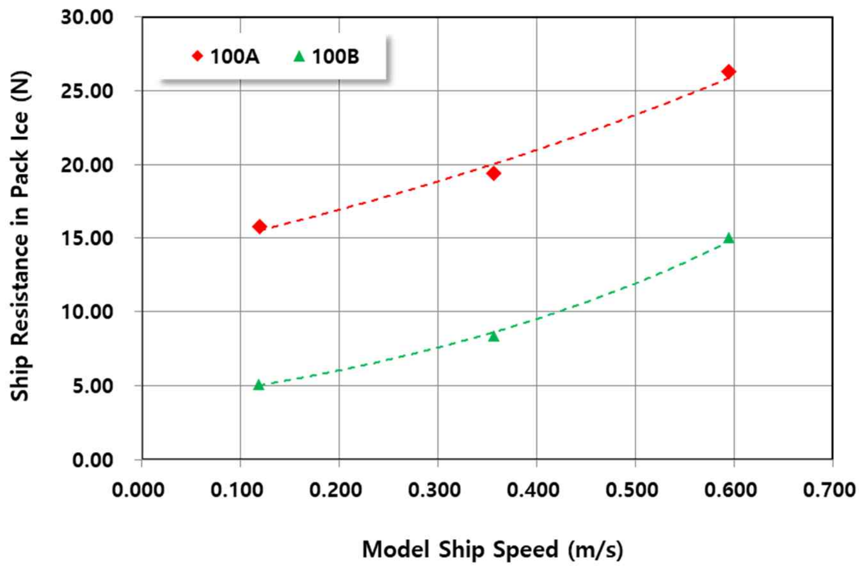

Figure 2. Model test results for two channel widths at 80% ice concentration

Table 3. Second model test conditions

Test No.	Channel width	Ice thickness (mm)	Remark
200A	2.8×B	40	-
200B	4.0×B	40	-
200C	6.0×B	40	-
200D	8.0×B	40	-
200E	10.0×B	40	-
200F	8.0×B	40	Confirm test of Test No. 200D

Figure 3. Various channel width conditions at 80% ice concentration

As mentioned above, the second model tests focused on the investigation of the magnitude of ship resistance in pack ice for various channel width conditions. The model test results are summarized in Table 4. At % Error calculation in Table 4, the target value is the channel width of 8 times beam (i.e. Test No. 200D). Figure 4 shows the ship resistance characteristics in pack ice for different channel width conditions. When the ship model enters a pack ice channel, the broken ice floes around the waterline area are pushed by the model hull. The broken ice floes push each other, which leads to an interference effect at the channel wall, and a ship resistance increment occurs. In particular, the magnitude of ship resistance in pack ice decreases when the channel width increases, but this decreasing trend converges when the channel width condition reaches 8 times the model ship beam.

Table 4. Model test results for various channel width conditions

Test No.	Model ship speed (m/s)	Ship resistance in pack ice (N)	% Error
200A	0.357	42.01	96.2
200B	〃	36.08	68.5
200C	〃	30.26	41.3
200D	〃	21.41	0.0
200E	〃	21.37	-0.2
200F	〃	21.26	-0.7

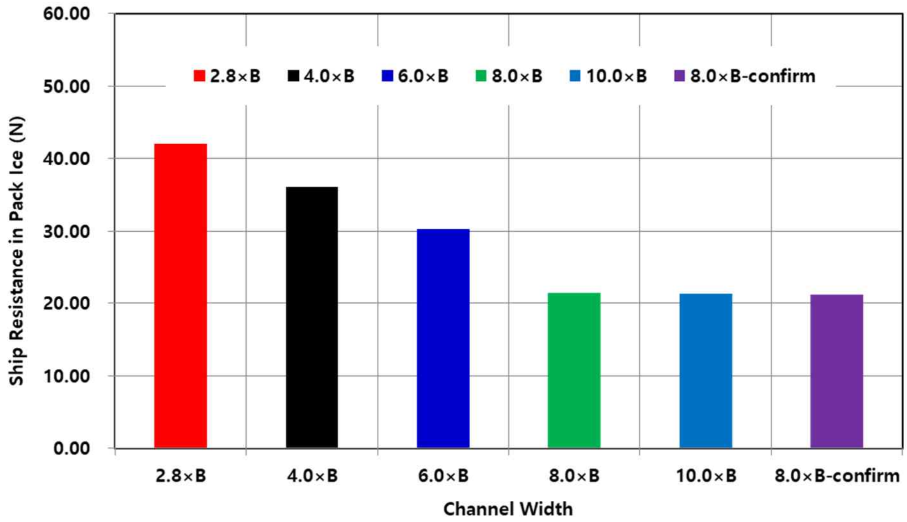

Figure 4. Ship resistance characteristics in pack ice with various channel widths

Figure 5 shows the underwater feature for channel widths of 4 and 8 times the beam. As the model ship enters the narrow pack ice channels, it displaces the broken ice floe. Some of the broken ice floes are submerged beneath the ship or pushed to the side. These ice floes can easily overlay one another, and this can cause a compressive force on the model ship. The ship resistance will therefore increase in the relatively narrow channel due to ice compression around the waterline area of model ship.

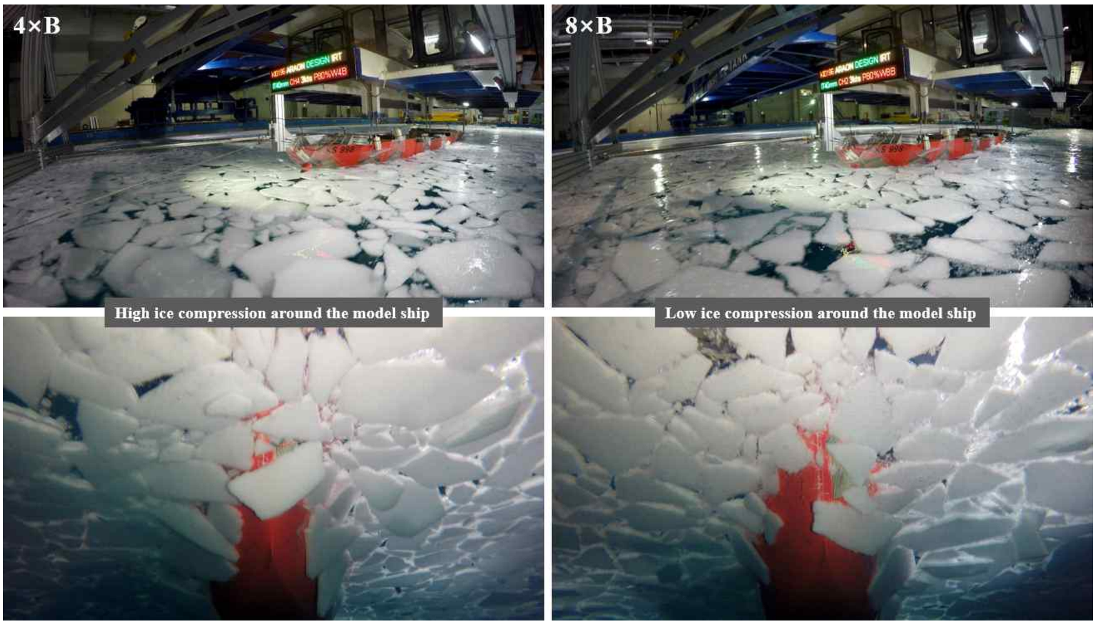

Figure 5. Underwater features for channel widths of 4 and 8 times the beam

The distribution of ice floes as the model ship passes through the pack ice channel is shown in Figure 6. The yellow, blue, and red dashed lines denote channel widths that are 4, 6, and 8 times the beam, respectively. When the model ship is moving through the pack ice channel, the broken ice floes may overlap one another, which further increases the ship resistance in the pack ice. More specifically, interactions between the broken ice floes are more frequent in channels below 4 times the beam, where the broken floes are pushed against the channel wall.

Regarding the movement of ice floes, there is no significant difference for channels between 6 and 8 times the beam, but ship resistance is higher at 6 times than 8 times beam for both 80% and 90% ice concentrations. Therefore, the reasonable channel width should be determined before the implementation of pack ice tests in an ice tank and high accuracy quantitative results could be obtained from the model tests.

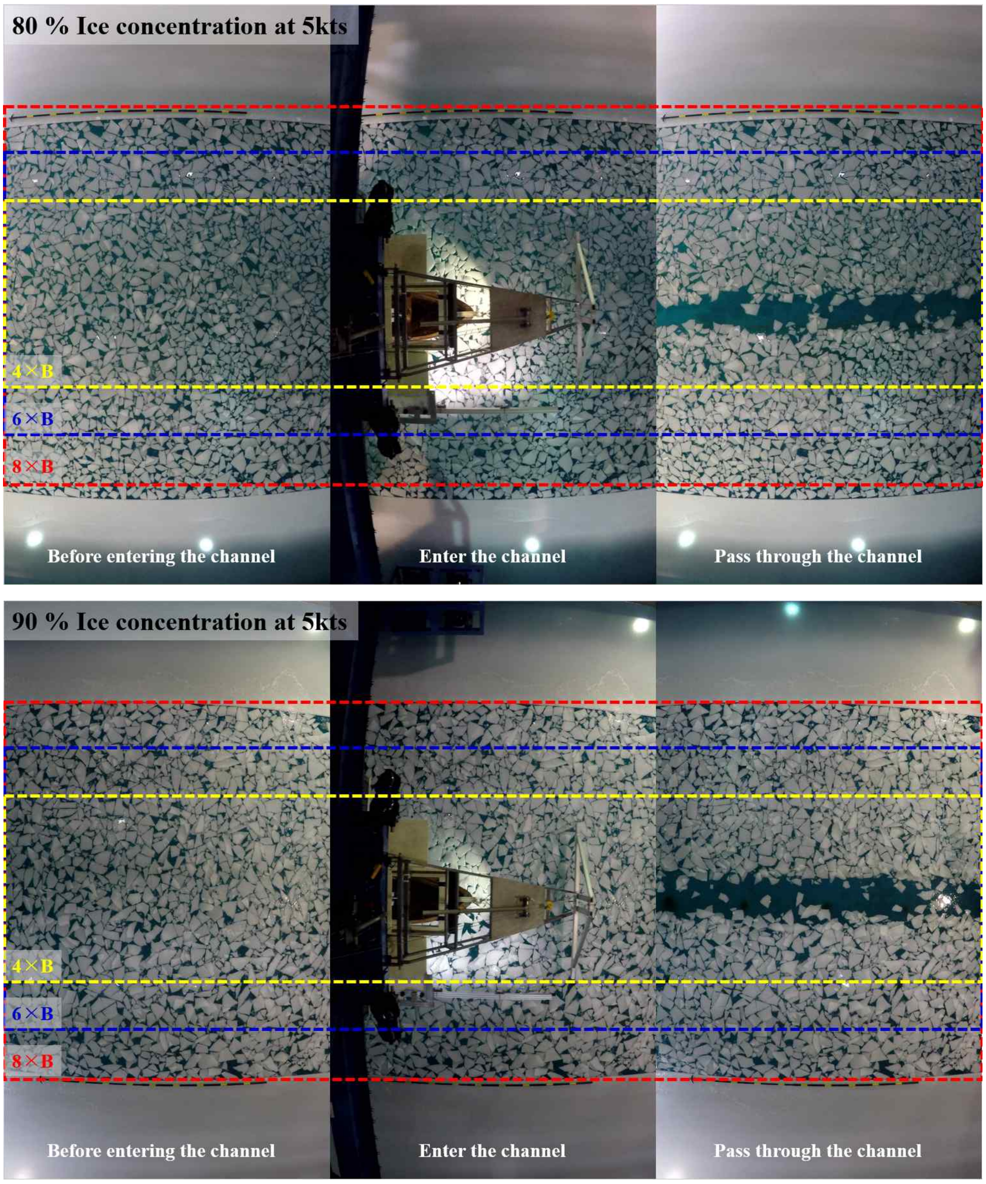

Figure 6. Bird's eye view of a channel width of 8 times the beam for two ice concentrations

To understand the ship resistance characteristics in pack ice, ice model tests were carried out with various ice thicknesses and concentrations. The test conditions are summarized in Table 5, and the results are shown in Figure 7. It appears that ship resistance in pack ice conditions tends to increase when the ice concentration and thickness increases. In Figure 7, the average magnitude of ship resistance at 80 mm ice thickness is approximately 8.5 times higher than the results at 26 mm ice thickness. In Figure 8, the increment ratio of ship resistance at each model ship speed shows a decreasing trend, and the ratio at 80% ice concentration is much higher than that at 90% ice concentration considering of ice thickness differences. The results demonstrate that the principle factor affecting ship resistance increment is the ice thickness in pack ice conditions of over 80% ice concentration.

Table 5. Third model test conditions

Test No.	Channel width	Ice thickness (mm)	Ice concentration (%)
300A	8.0×B	26	80
300B	8.0×B	80	80
300C	8.0×B	26	90
300D	8.0×B	65	90

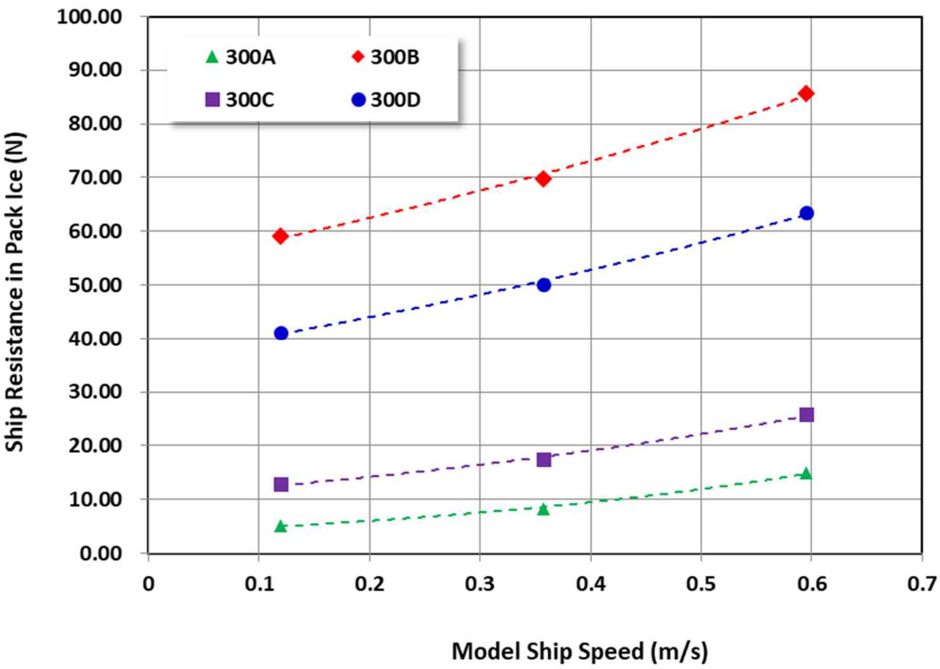

Figure 7. Ship resistance characteristics in pack ice with various ice thicknesses and concentrations

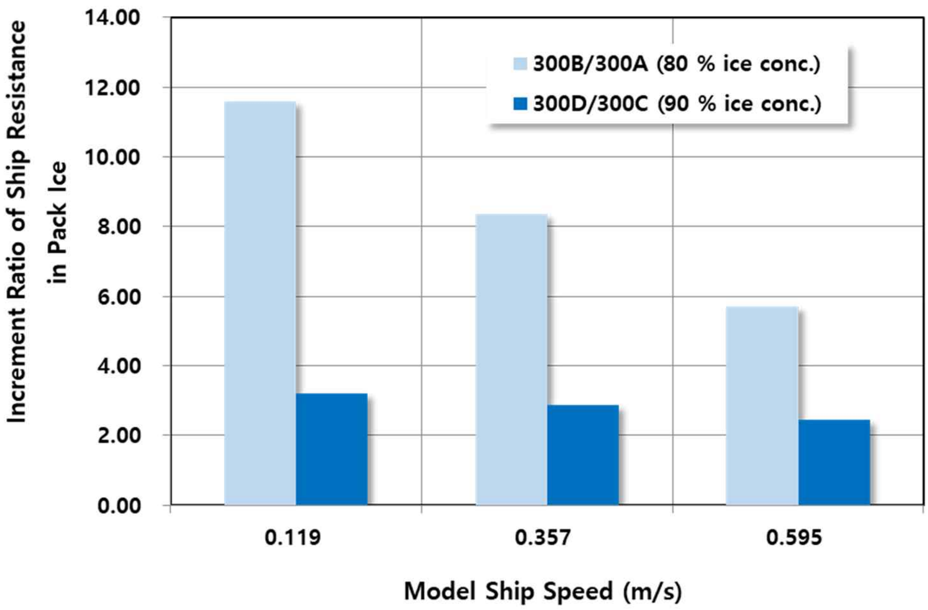

Figure 8. Increment ratio of ship resistance in pack ice for two ice concentrations

CONCLUSIONS

This study focused on understanding ship resistance characteristics in pack ice to increase the accuracy of the model test results. Test conditions, such as ice concentration and thickness, are critical parameters from the perspective of ship performance. Channel width is also a significant factor and is related to the accuracy of ice test results. Appropriate channel widths should thus be determined to obtain quantitative results with the highest possible accuracy.

Throughout the series of model tests, the phenomena of broken ice floes around the model ship overlapping and pushing against the channel wall were observed with a channel width of 6 times the beam of the ship model. Ship resistance under these conditions increases due to the ice compression at the waterline area of the ship model and the channel wall. From the model tests, a reasonable channel width was found to be 8 times the beam of the model ship. In addition, ship resistance increases when the ice thickness and concentration increases, while the ship resistance increment ratio at each model ship speed tends to decrease. The dominant factor affecting increments in ship resistance is ice thickness in pack ice conditions of over 80% ice concentration.

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